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FEASIBILITY OF A MESHLESS  
STORAGE TUBE

N. H. Lehrer  
Quantum Physics Department

Interim Scientific Report No. 3  
15 September 1962 — 14 January 1963

Contract AF 33(697)-7789  
Task Number 41653

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STORAGE TUBE

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## ABSTRACT

The objective of this work is to conduct a systematic study of bombardment-induced-conductivity (BIC) materials which can be used to demonstrate the feasibility of a meshless storage tube.

Studies were conducted on a large number of BIC layers, many of which exhibited substantial conductive memory effects as a result of electron-beam excitation. Data are presented which characterize the sustained BIC in these films. These data represent the following:

1. The volt-ampere characteristic
2. The effect of bombarding electron beam energy and applied field both on the instantaneous BIC response and on the sustained change in conductivity
3. The effect of the excitation energy on the sustained change in conductivity
4. The effect of the applied voltage and sustained currents on the change in the capacitance.

Analysis of the data indicates that while the magnitude of the sustained conductivity change is adequate, both the unexcited conductance and thickness of the sustained BIC layers must be increased to effectively modulate the voltage drop across a thin electroluminescent film.

An elementary model is proposed to explain some aspects of the behavior of the conductive memory effect. An important element of this model is the existence of a barrier at one of the electrodes.



## I. INTRODUCTION

The key problem in demonstrating the feasibility of a meshless storage tube is to produce a material which possesses the appropriate sustained BIC properties. That is, the material must exhibit an increase in conductivity of several orders of magnitude when bombarded for microseconds by an electron beam. Upon cessation of bombardment, this increased conductivity must be maintained. In addition, the conductivity of the material must be restored to its prebombarded value by removal of the electric field or by a similar technique. As discussed in Interim Scientific Report No. 2, the search for a suitable material is primarily an experimental one because of the absence of any substantive theory of sustained BIC to serve as a guide. As a result of our investigations, a material has been found which sometimes demonstrates strong conductive memory effects induced by electron bombardment or light. This conductivity effect is reversible in that the conductivity of the sample can be restored to its prebombarded value by momentary reversal of the field. Since this phase of the investigation has actually just begun, it is not always possible to obtain reproducible results and the effect is far from understood. The purpose of this report, therefore, is to present a picture of the relevant parameters which characterize the effect. These data will serve as a guide in determining the suitability of applying the effect to the meshless storage tube as well as other devices and also will contribute to an understanding of the mechanism.

The target configuration and the measurement circuits and technique employed in these studies are the same as those reported in Interim Scientific Report No. 1. All dielectric layers were nominally  $1/2 \mu$  thick.

## II. DATA

### A. Volt-Ampere Characteristics

The dc volt-ampere characteristic was measured on virtually all targets which were fabricated. These characteristics tend to fall into two general groups. In one group the current is symmetrical with voltage, i.e., the absolute value of the current is the same for positive and negative applied voltages. The leakage current is on the order of microamperes when the applied voltage is 1 V. None of these layers exhibit sustained BIC.

In the second group the volt-ampere characteristic is highly asymmetrical, as illustrated in Fig. 1. In this case, the current through the dielectric is orders of magnitude less when the applied voltage is negative, i.e., when the bottom electrode, which is on the glass substrate, is at a lower potential than the top one. The sustained currents are noted under conditions of negative applied field in layers which exhibit this highly asymmetrical volt-ampere characteristic. However, not all layers having rectifying characteristics exhibit memory effects. In Fig. 2 a detailed forward characteristic is shown. Analysis of the data indicates that the current varies with approximately the fourth power of the voltage. In Fig. 3 a detailed reverse characteristic is shown. Here the current varies approximately as the 1.83 power of the voltage. The rectification ratio, which is the current at a particular positive value of the applied voltage divided by the current at the corresponding negative value of the field, is shown in Fig. 4. The maximum value of the rectification ratio is about 7000. Note that the increase is exponential with voltage and is limited only by the breakdown of the sample. When the voltage across the layers exceeds about 1.5 V in the negative direction, irreversible breakdown occurs. The result of this breakdown is to increase the leakage current in the reverse direction to such an extent that the volt-ampere characteristic becomes symmetrical. The memory characteristic is destroyed as a result of the breakdown.

### B. Conduction Ratio Versus Primary Beam Energy and Applied Voltage

The instantaneous response of the layers exhibiting sustained BIC was examined over a wide range of beam energies and applied voltages, under conditions of both pulsed and continuous bombardment. The wave form of the input pulse is shown in Fig. 5. A 1  $\mu$ A 150  $\mu$ sec pulse was typically employed. The technique of "setting" the dielectric which was discussed in Interim Scientific Report No. 1, p. 18, was employed for taking measurements of the response to a single pulse. The purpose of this "setting" is to place the dielectric in a condition independent of previous history to achieve reproducible results. This is done by bombardment of

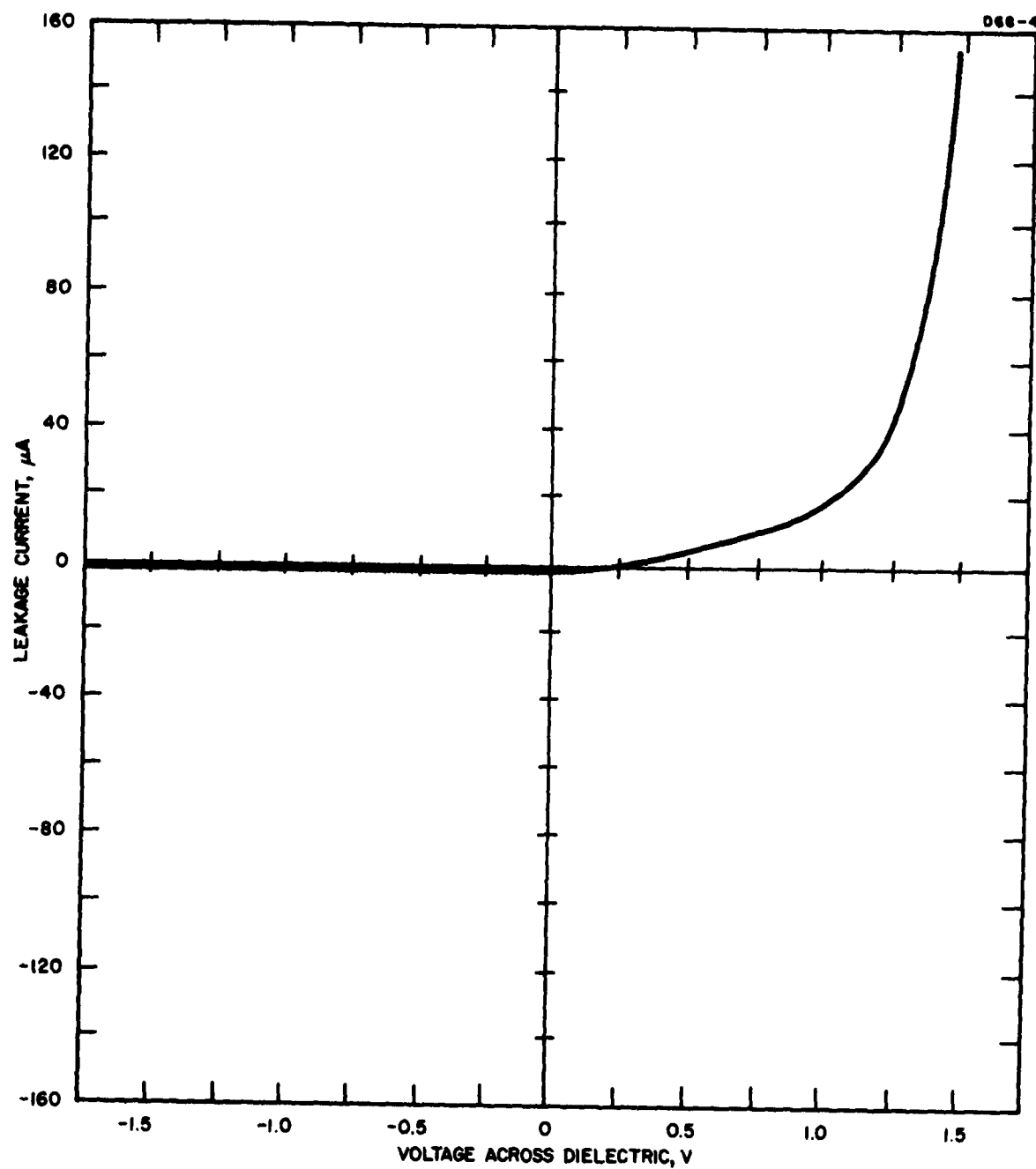


Fig. 1. Volt-ampere characteristic of typical sustained BIC layer.  
Film thickness  $1/2 \mu$ . Target No. 221-A-1R.

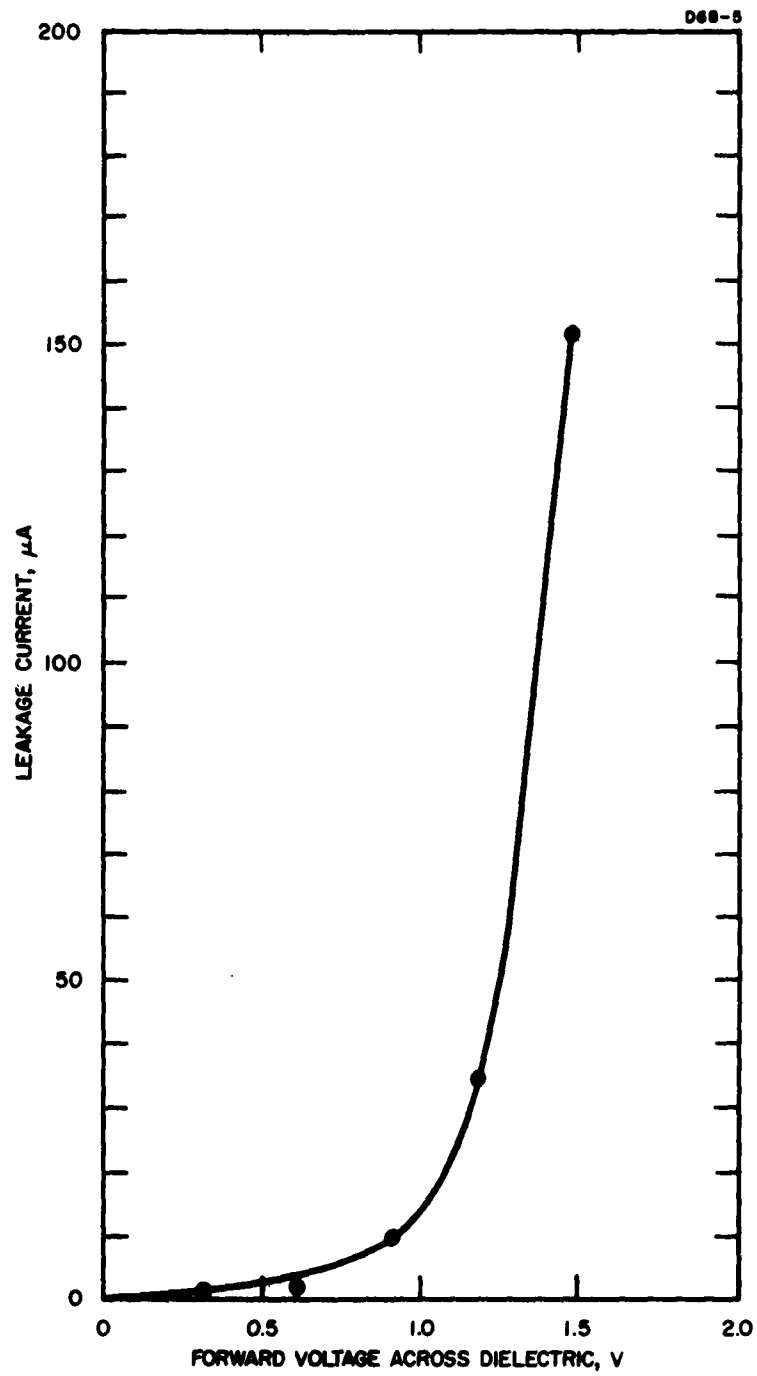


Fig. 2. Detailed forward characteristic. Target No. 221-A-1R.

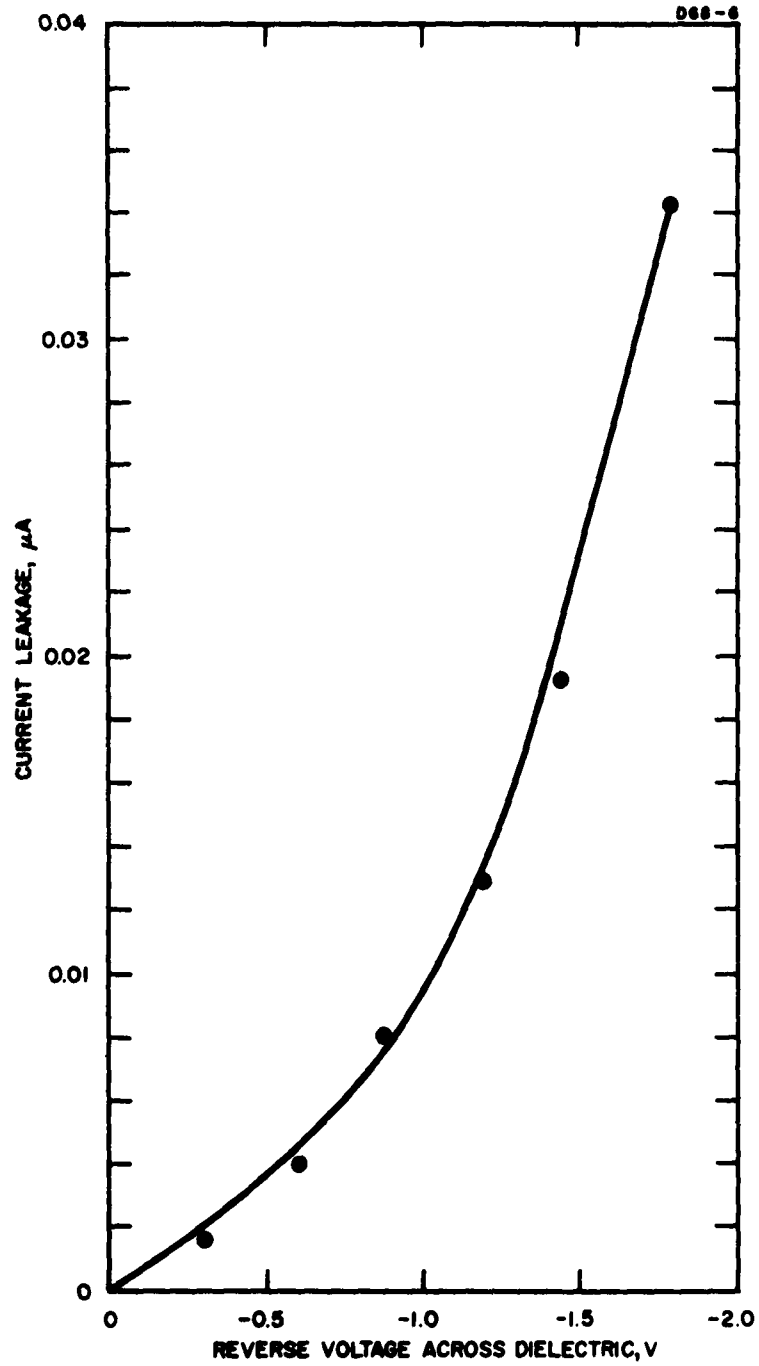


Fig. 3. Detailed reverse characteristic. Target No. 221-A-1R.

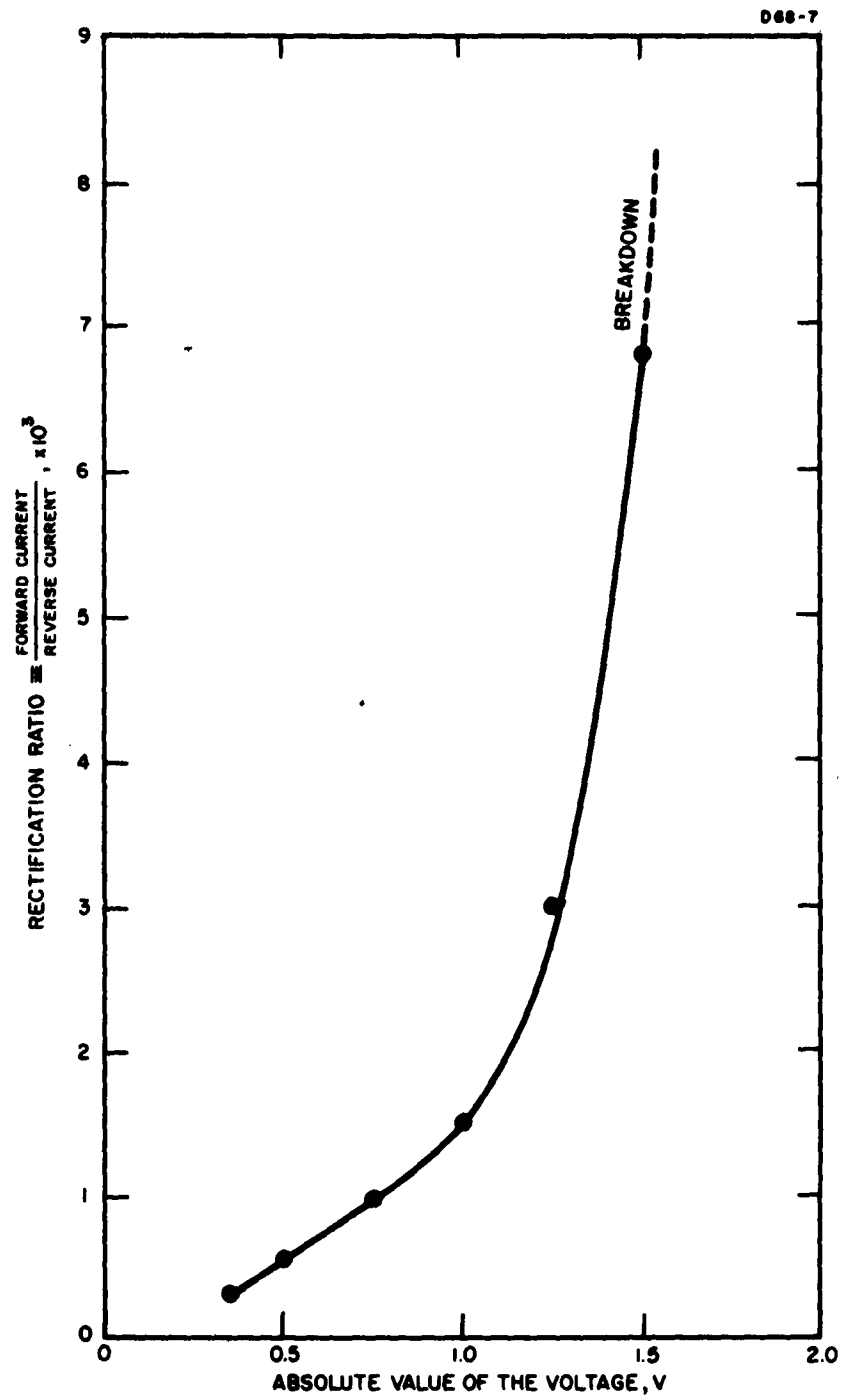


Fig. 4. Rectification ratio versus voltage across film.  
Target No. 221-A-1R.

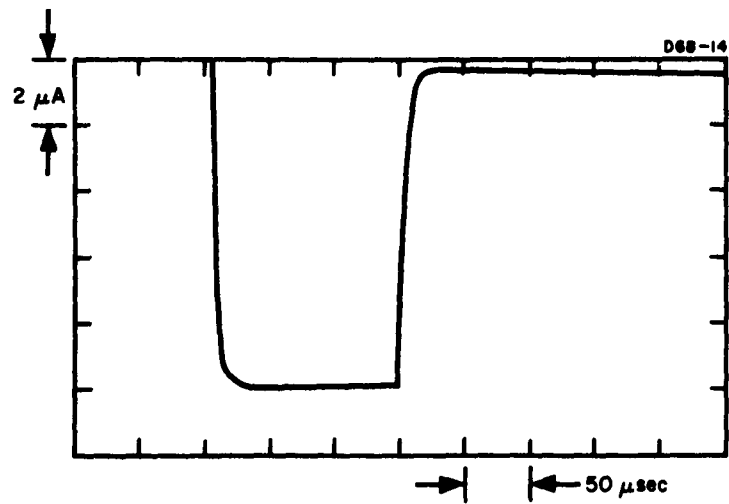


Fig. 5. Bombarding electron beam input pulse. Vertical scale  $0.2 \mu A/cm$ , horizontal scale  $50 \mu sec/cm$ .

the target for 3 to 4 sec until the response is stabilized while zero field is applied across the dielectric. In Fig. 6 the output pulse of the dielectric is shown. These data were obtained with a negative applied voltage. In Fig. 7 the decay of the peak pulse gain with repeated pulses is shown. Note that the final value to which the gain decays is that which the dielectric exhibits under repeated bombardment.

In Fig. 8 the conduction ratio is shown as a function of the primary beam energy. Both the peak pulse gain and dc bombardment data were taken with - 1.5 V applied. It is interesting to note that when a positive voltage is applied across the dielectric, the peak pulse and dc values of the conduction ratio are an order of magnitude less than under conditions of negative applied field. This is in contrast to observations made on layers which did not exhibit the memory effect and where high values of the gain were sometimes observed in both directions. The shape of the curves shown in Fig. 8 is typical of BIC in thin films.

In Fig. 9 the effect of the applied field on the conduction ratio is shown. Again the linear change in the conduction ratio with increasing field is typical of the BIC effect.

#### C. Effect of Primary Beam Energy and Applied Voltage on Sustained BIC

In studying the effect of variations in bombarding beam energy and applied voltage, we are particularly concerned with the manner in which the conductivity of the bombarded region changes after excitation. Because the application of the conductive memory to the meshless storage tube involves switching of voltages, this change in conductivity is evaluated most significantly in relation to the prebombarded conductivity of the target. The sustained change in relative conductivity  $\Delta g/g$  is calculated from the following formula:

$$\frac{\Delta g}{g} = \frac{i_s - i_1}{\frac{i_1}{4}}$$

when  $i_s$  is a current flowing through the dielectric after bombardment has ceased and  $i_1$  is the current flowing through the dielectric before bombardment. Because only one-quarter of the area of the target is bombarded,  $i_1/4$  appears in the denominator of the above expression. In Fig. 10  $\Delta g/g$  is plotted as a function of the primary beam energy. The upper curve shows the change in conductivity immediately following bombardment during a 10 sec period with 600 pulses each of which was 150  $\mu$ sec long and 1  $\mu$ A in



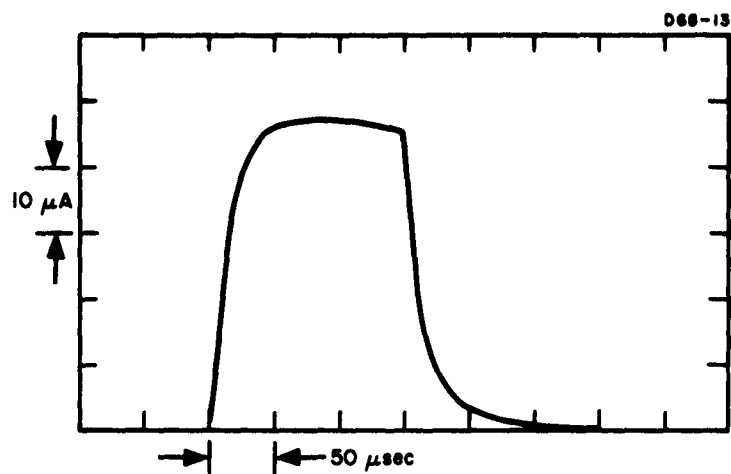


Fig. 6. Peak pulse gain. Primary beam energy 14 kV, current  $1 \mu A$ , applied voltage -1.5 V. Target No. 225-B-2R.

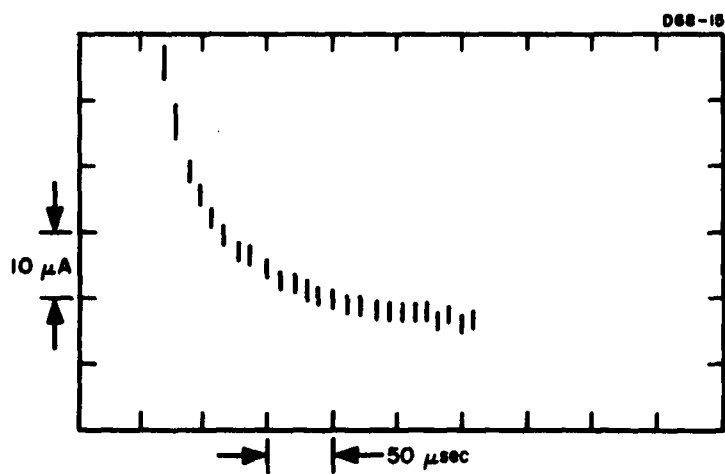


Fig. 7. Decay of peak pulse gain. Target No. 212-B-1L.

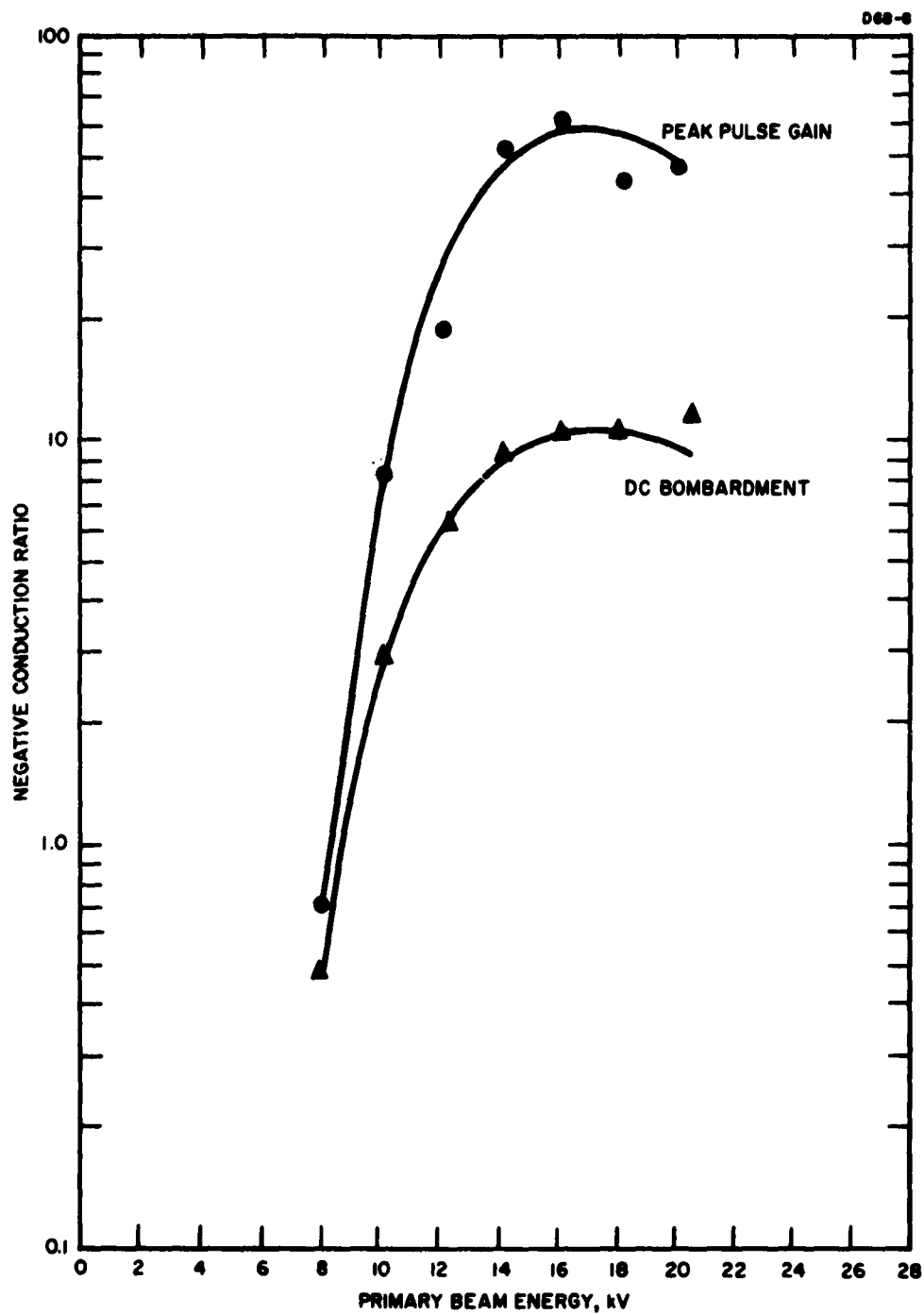


Fig. 8. Conduction ratio versus primary beam energy. Electric field across dielectric  $-3 \times 10^4$  V/cm. Target No. 225-A-3R.

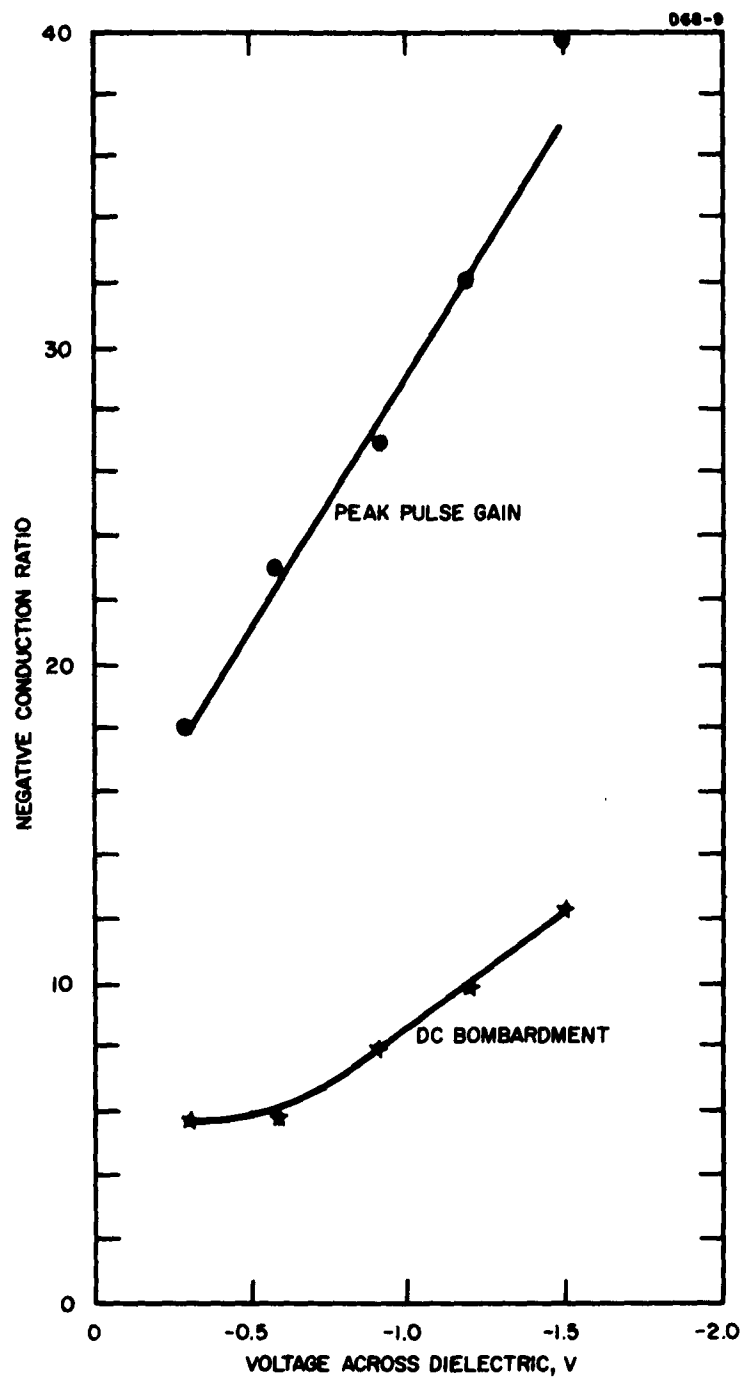


Fig. 9. Conduction ratio versus voltage across film. Primary beam energy 14 kV. Target No. 225-B-3R.

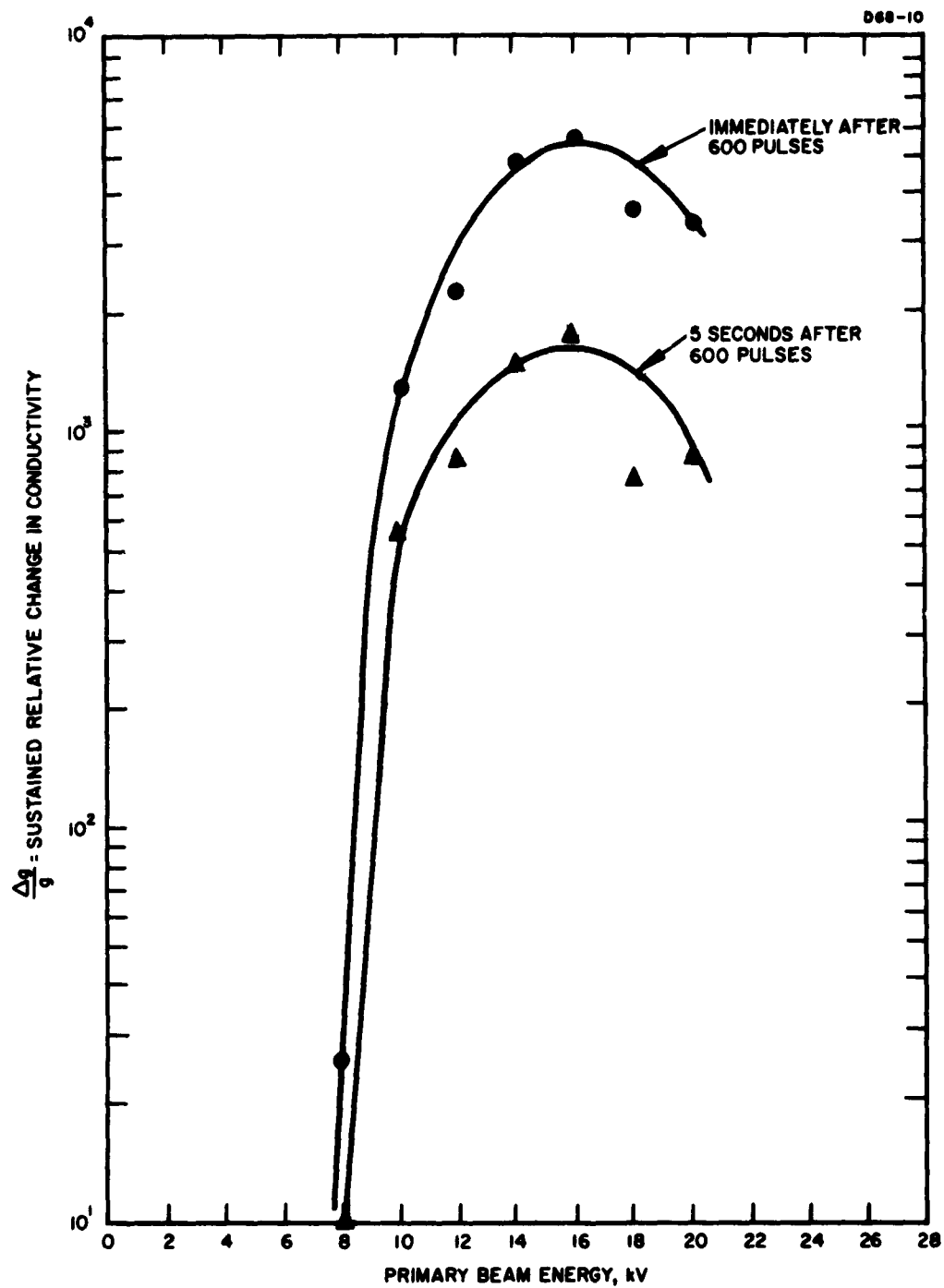


Fig. 10. The relative sustained change in conductance versus primary beam energy. Primary beam current  $1 \mu\text{A}$ , pulse length  $150 \mu\text{sec}$ , number of pulses 600, electric field across dielectric  $-3 \times 10^4 \text{ V/cm}$ , beam diameter 0.25 cm. Target No. 225-A-2R.

beam current. The lower curve represents  $\Delta g/g$  5 sec after bombardment has ceased. Note that the maximum change in conductivity, obtained as a result of this excitation, is almost four orders of magnitude greater than the prebombarded conductivity. It is of interest that the general shape of these curves for the sustained conductivity effect is similar to the curves obtained for the instantaneous BIC response shown in Fig. 8. At low values of beam energy, the effect is negligible. It increases sharply at about 8 to 10 kV and reaches a maximum at 14 to 16 kV, decreasing thereafter. These measurements were made with 1.5 V across a 0.5  $\mu$  film. It is at this applied voltage that the greatest value of  $\Delta g/g$  is obtained. As shown in Fig. 4, this also corresponds to the voltage at which the maximum rectification ratio is obtained before breakdown. The effect of the applied voltage on the sustained conductivity is shown in Fig. 11. As in the case of the instantaneous BIC response, the sustained response is linear over most of the applied voltage. However, there is some suggestion of saturation at the highest applied fields.

#### D. Change in Conductance Versus Excitation Energy

In Fig. 12, the change in conductivity is shown as a function of the number of excitation pulses. Although not evident in the curves, the effect of the first few pulses is relatively negligible. With succeeding pulses, the sensitivity increases. There is some suggestion of saturation for large numbers of pulses.

Computation of the energy delivered per unit area by each pulse can provide an indication of the sensitivity of the layers to excitation.

The energy contained in each 14 kV, 1  $\mu$ A, 150  $\mu$ sec pulse of electrons is given by

$$E = V_p I t = 14 \times 10^3 \times 1 \times 10^{-6} \times 150 \times 10^{-6} = 21 \times 10^{-7} \text{ J}$$

where  $V_p$  is the primary beam energy,  $I$  is the primary beam current and  $t$  is the pulse duration. The energy per unit area is given by

$$\frac{E}{A} = \frac{E}{\frac{\pi D^2}{4}} = \frac{21 \times 10^{-7}}{0.049} \text{ J/cm}^2 = 0.43 \times 10^{-4} \text{ J/cm}^2.$$

Thus, each pulse delivers  $43 \mu\text{J/cm}^2$ . From the curves in Fig. 12, it can be seen that 50 such pulses change the conductivity by a factor of 1000. Therefore  $50 \times 43 \mu\text{J/cm}^2$  or  $2150 \mu\text{J/cm}^2$  can change the conductivity by a factor of 1000. If we assume more practical conditions for the spot size and current of the primary beam, then a writing speed can be computed for the sustained BIC layer.

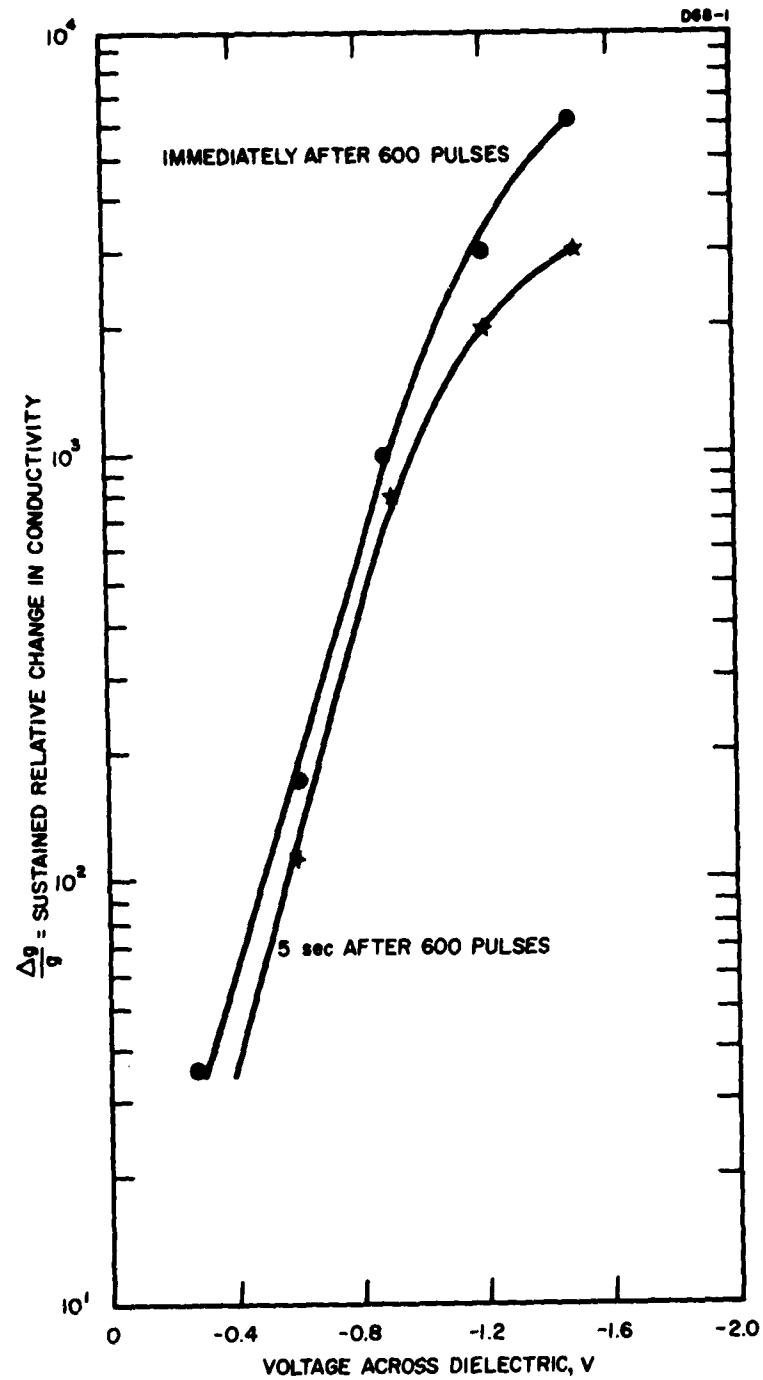


Fig. 11. The relative sustained change in conductance versus voltage across the dielectric. Primary beam energy 14 kV, primary beam current 1  $\mu$ A, pulse length 150  $\mu$ sec, number of pulses 600, beam diameter 0.25 cm. Target No. 225-A-2R.

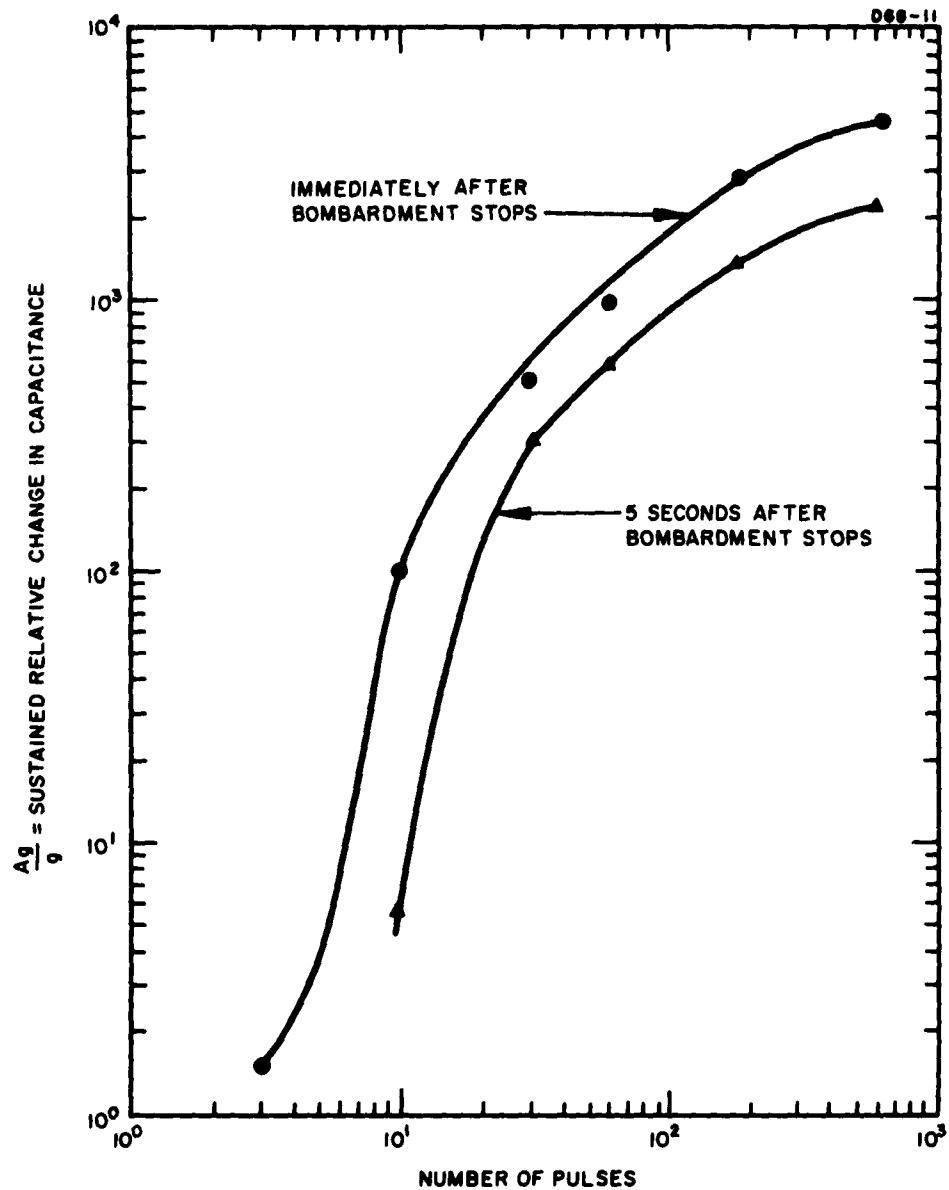


Fig. 12. The relative sustained change in conductances versus number of exciting pulses. Primary beam energy 14 kV, primary beam current 1  $\mu$ A, pulse length 150  $\mu$ sec, beam diameter 0.25 cm, applied field  $-3 \times 10^4$  V/cm. Target No. 225-B-1L.

The power per unit area  $P/A$  delivered by a 14-kV, 25  $\mu$ A electron beam with a 0.01 in. spot size is

$$\frac{P}{A} = \frac{V_p I_p}{A} = \frac{14,000 \times 25 \times 10^{-6}}{490 \times 10^{-6}} \text{ W/cm}^2 = 660 \text{ W/cm}^2 .$$

Now  $2150 \mu\text{J/cm}^2$  is required to change the conductivity by a factor of 1000. To compute the required pulse length  $t$  of the primary electron beam,

$$t = \frac{2150 \times 10^{-6}}{660} \cong 3.2 \mu\text{sec} .$$

This means that the beam can increase the sustained conductivity of the bombarded spot 1000 times in  $3.2 \mu\text{sec}$  — a reasonable figure in terms of many display requirements.

#### E. Effect of Applied Voltage and Sustained Currents on Capacitance

Measurements made on layers exhibiting sustained BIC reveal that not only does the capacity change with applied voltage, but even at constant voltage it varies with the sustained conductivity. Assuming a dielectric constant of 10, the capacitance of the layer based on geometrical considerations is computed to be about  $0.5 \times 10^{-8}$  F. This figure can be compared with the curve shown in Fig. 13 where the value of the capacity varies between 1 and  $40 \times 10^{-8}$  F with field.

Even at constant values of the applied voltage, the leakage current through the dielectric has an effect on the capacitance. This effect is shown in Fig. 14. These changes in capacitance with applied voltage must be considered in any application where switching of voltages is involved because the change in conductivity will affect not only the conductance of the layer but also the capacitance.

#### F. Erasure

A brief investigation was conducted of the effect of forward voltage pulses on the sustained currents when the dielectric is operated in the reversed biased condition. It was found that the sustained BIC could be completely erased by application of a forward voltage pulse several milliseconds in duration and equal in magnitude to the reverse voltage. The original conductance of the dielectric is completely restored a few seconds after the application of the forward voltage pulse. The erasure restoration time appears to be shortened by increasing the amplitude of the forward voltage pulse.



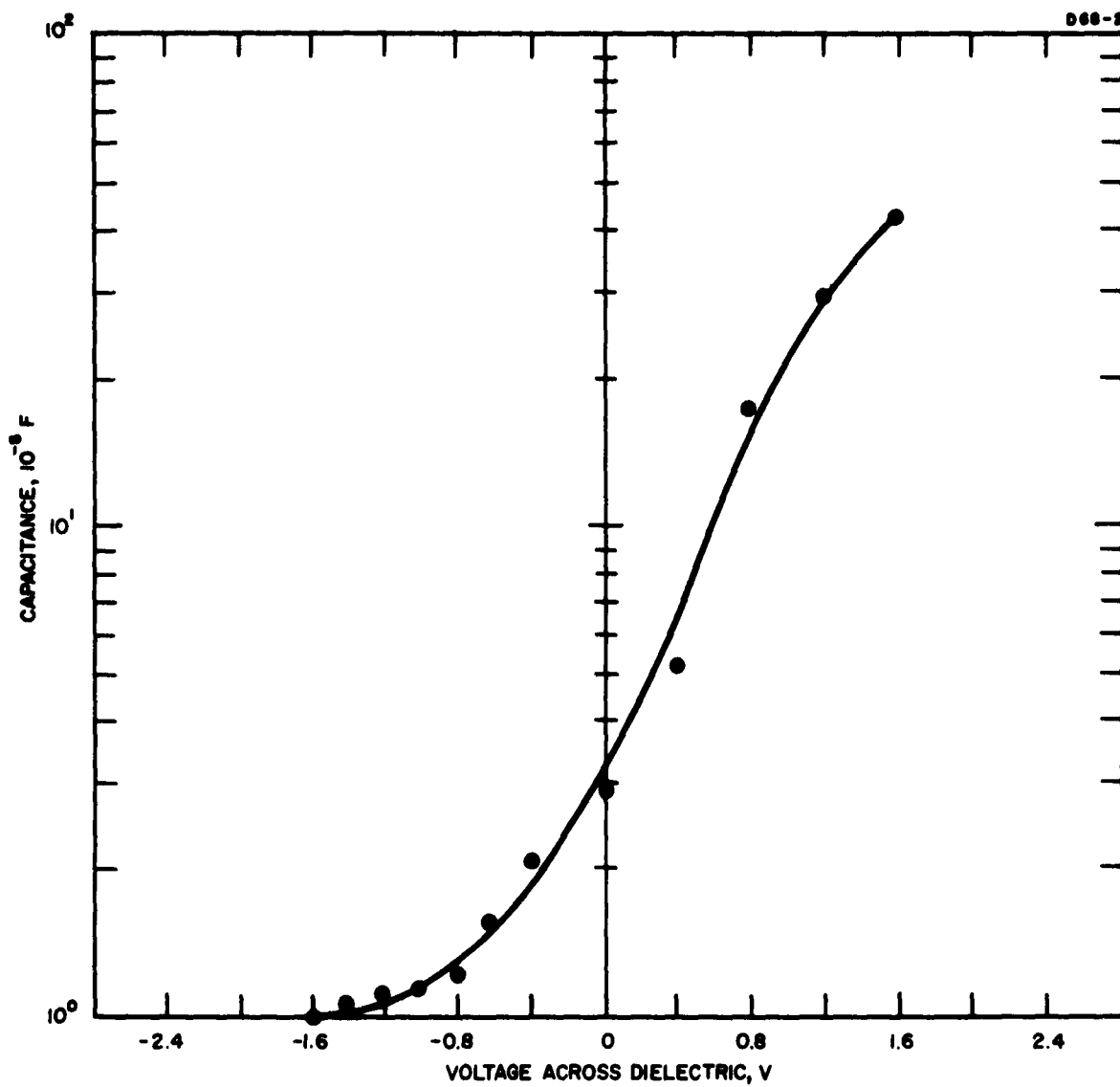


Fig. 13. Capacitance versus applied voltage. Frequency 1 kc, 0.25 mV signal. Target No. 225-B-1L.

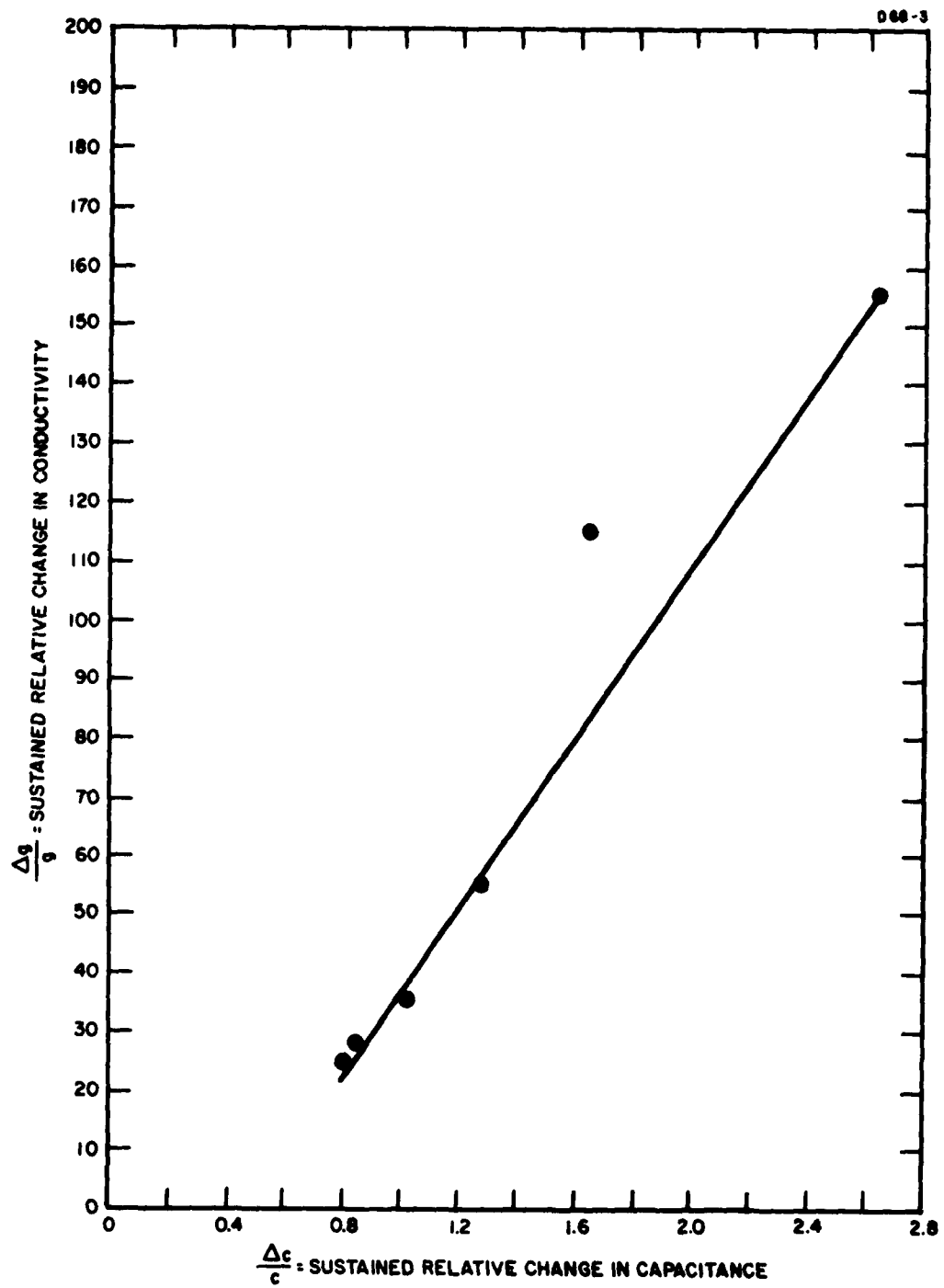


Fig. 14. Capacitance versus sustained currents. Target No. 212-B-1L.

### III. APPLICATION TO THE MESHLESS STORAGE TUBE

The applicability of the sustained BIC effect described in this report to voltage switching in the meshless storage tube can be evaluated on the basis of the analysis "Establishment of Required BIC Characteristics" presented in Interim Scientific Report No. 1, p. 2. That analysis indicates that in the unexcited condition the voltage division between the EL (electroluminescent) and BIC layers is determined by the ratio of their elemental capacitances. This can be understood by considering that when an ac voltage is applied, the equivalent susceptance of the EL layer is substantially greater than its parallel equivalent conductance. Therefore,

$$\frac{V_{BIC}}{V_{EL}} \cong \frac{c_{EL}}{c_{BIC}} \cong \frac{d_{BIC} K_{EL}}{d_{EL} K_{BIC}}$$

where  $V_{BIC}$ ,  $V_{EL}$  are the voltage drops across the BIC and EL layers, respectively;  $c_{BIC}$ ,  $c_{EL}$ ,  $d_{BIC}$ ,  $d_{EL}$  and  $K_{EL}$ ,  $K_{BIC}$  are the elemental capacitances, thicknesses and dielectric constants, respectively, of the two layers. The ratio

$$p = \frac{c_{EL}}{c_{BIC}}$$

should be as large as possible, with a minimum value of 10, if the EL layer is to be modulated over an adequate luminance range.

In the case of a  $1/2\text{-}\mu$  EL layer having a dielectric constant of 10, and assuming a minimum  $p$  value of 10,

$$p = 10 = \frac{c_{EL}}{c_{BIC}} = \frac{t_{BIC} K_{EL}}{t_{EL} K_{BIC}} = \frac{t_{BIC} 10}{5 \times 10^{-7} K_{BIC}}$$

Solving the above equation,

$$\frac{t_{BIC}}{K_{BIC}} = 5 \times 10^{-7} \text{ m.}$$

From the data presented in Section II, Part E, a reasonable value for the dielectric constant in the sustained BIC layer is about 20. Using this value for  $K_{BIC}$  in the above equation,

$$t_{BIC} = 5 \times 10^{-7} K_{BIC} = 4 \times 10^{-7} \times 20 = 10^{-5} \text{ m}$$

or

$$t_{BIC} = 10 \mu$$

This is almost 20 times the thickness of the present sustained BIC layers.

The analysis in Interim Report No. 1 also indicates that the ratio

$$R = \frac{g_{BIC}}{\omega c_{BIC}} = \frac{\text{conductance of BIC layer}}{\text{susceptance of BIC layer}},$$

must change from about 0.1 to 10 to switch the voltage across the EL layer. For the unexcited case,

$$R_{un} = \frac{g_{BIC}}{\omega c_{BIC}} = \frac{\frac{A}{d\rho}}{\omega K_{BIC} \epsilon_0 \frac{A}{d}} = \frac{1}{\omega K_{BIC} \epsilon_0 \rho}$$

where  $\epsilon_0$  is the permittivity of free space and  $\rho$  is the resistivity of the unexcited BIC layer. A value of  $\rho = 10^9 \Omega\text{-m}$  can be obtained from the volt-ampere curve in Fig. 3 using the slope of the curve between - 1.25 and 1.75 V. Assuming a frequency of 10 kc,

$$R_{un} = \frac{1}{2\pi \times 10^4 \times 20 \times 9 \times 10^{-12} \times 10^9} \cong 10^{-4}.$$

This is considerably less than the minimum required value  $R_{un} = 0.1$ . For the excited case, taking the maximum value of  $\Delta g/g$  as  $10^4$  based on the data in Fig. 11 and ignoring capacitance changes in the BIC layer resulting from the sustained currents,

$$R_{\text{ex}} = 10^4 R_{\text{un}} = 10^4 \times 10^{-4} = 1 .$$

This  $R$  is a factor of 10 less than the value needed for optimum switching of the EL layer.

The voltage required to drive an EL phosphor must also be considered. Usually applied fields of  $10^5$  V/cm are needed, i.e., about 5 V across a  $1/2$ - $\mu$  film. This compares with operating voltages of 1.5 V for the sustained BIC layers.

It should be pointed out that the sustained BIC currents are dc in nature and reversal of the field across the dielectric causes them to cease. The foregoing analysis is predicated on the assumption that the eventual mode of operation will be a biased ac operation compatible with both the EL and BIC layer voltage requirements.

The following table summarizes the results of this analysis:

BIC Characteristic	Desired	Attained
Film Thickness	$10 \mu$	$1/2 \mu$
$\frac{g_{\text{BIC}}}{\omega c_{\text{BIC}}}$ (unexcited)	0.1 or less	$10^{-4}$
$\frac{g_{\text{BIC}}}{\omega c_{\text{BIC}}}$ (excited)	10 or more	1
Switching Voltage	5 to 10 V	1.5 V

#### IV. THEORETICAL INTERPRETATION OF SUSTAINED EFFECTS

The essential data on the sustained BIC effect can be summarized as follows:

1. Without external excitation, i.e., light or electron beam, very strong rectification effects are observed, up to a rectification ratio of  $10^4$ .
2. With the sandwich back-biased, external excitation produces a strong increase in conductivity.
3. Upon removal of the external excitation and continued application of the voltage, continuing high conductivity is observed.
4. Upon reduction of the applied voltage to zero, or reversal of it, the film returns to the low conductivity state.
5. These effects are repeatable.

Any model proposed for this system must be consistent with (1) through (5). The most unusual features of the experimental results are the existence of the sustained currents and the erasure of these currents by a voltage reversal. A model to account for these heretofore unreported results will probably require novel features.

The unexcited rectification effect demonstrated in Fig. 4 implies the existence of a barrier at the back aluminum electrode. A distribution of interparticle barriers in the bulk of the film, as discussed by Bube,<sup>1</sup> does not give rise to this anisotropy in conduction. The actual type of barrier, i.e., metal-semiconductor, surface state, etc., remains open to speculation and provides an interesting area for investigation. However, general theoretical features common to many varieties of barriers are depicted in Fig. 9. The essential feature of this barrier is the depletion region containing ionized donors.

It has been shown that external excitation can change the character of a barrier between the three generally classified types<sup>2</sup>: ohmic (injecting), neutral (flat band), and blocking (rectifying). The barrier potential, in the blocking contact of Fig. 9, is maintained by the field of the ionized donors as illustrated in Fig. 15. If photoexcited, or electron beam excited, charge can neutralize this depletion region charge, the barrier becomes neutral. Bube<sup>3</sup> has reported such action in CdS crystals.

Assuming that the excited charge can overcompensate the ionized donors of the depletion region, the possibility exists for converting the original blocking contact into an ohmic (injecting) one. This opens up

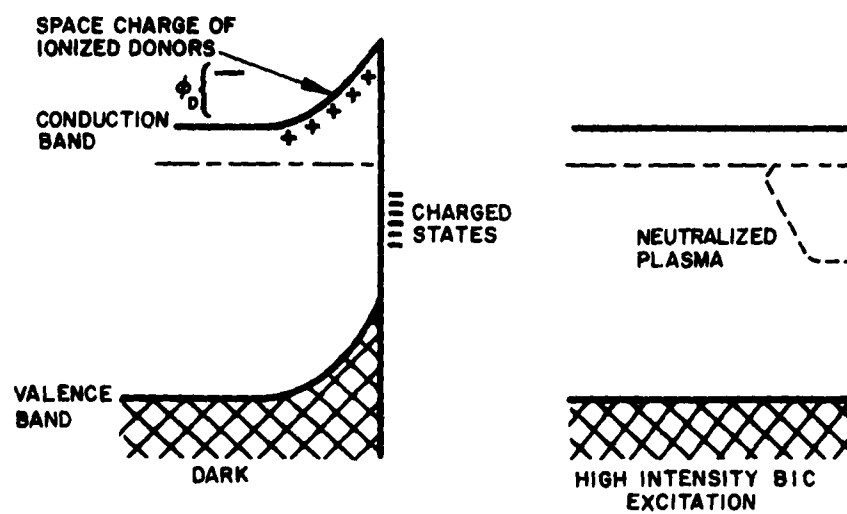


Fig. 15. Energy-level diagram for lower electrode barrier.

the possibility for injection currents in addition to photoexcited currents. These injection currents would not be readily observable when present together with the photoexcited or BIC currents if their magnitude were less than a tenth of the photocurrents. These injection currents could, however, provide a mechanism for the sustained currents which are observed experimentally when the external excitation is removed.

In order that the experimentally observed sustained currents be associated with injection currents, it is necessary that the energy band remain depressed after the photoexcitation or BIC excitation is removed. If the density of ionized centers associated with work function differences between, say metal-semiconductors, is saturated by the density of injected charge, it is conceivable that the injected charge (current) can maintain itself by holding down the band edge. If the applied voltage is taken to zero or reversed, the back contact turns to its normal blocking state and the sustained current is destroyed. The cycle of events leading to sustained current can be reinstated by another pulse of light or electrons. The model we have in mind then has the following features:

1. Before photoexcitation, the dielectric has one ohmic contact and one blocking contact at the back electrode, causing rectification.
2. During photoexcitation, the blocking contact is converted to an injecting one through donor neutralization, and injection currents become possible.
3. Upon removal of the photoexcitation, but with continuing application of the field, the injection currents maintain themselves by filling the ionized donor centers and holding down the conduction band edge.
4. Upon removal of the applied voltage, the injection currents are destroyed, the back electrode returns to a blocking state, and further excitation is needed to re-trigger the injection currents.

Many features of this model are borne out by the experimental data presented in the previous sections. As already pointed out, the interpretation of the data of Figs. 1 and 2 requires a barrier at the back electrode. The existence of ionized donor states is demonstrated in Fig. 13 since a voltage dependent capacitance is generally associated with barriers containing such states. The data of Fig. 2 (when plotted) show a dependence of forward current on the fourth power of voltage as could be expected from injection currents in a material with a nonuniform trap distribution.



## V. CONCLUSIONS

The following conclusions can be drawn from the experimental data presented:

1. A material has been found which exhibits strong conductive memory effects as a result of electron beam excitation.
2. The conductive memory effect is reversible in that momentary reversal of the field restores the dielectric to its prebombarded conductivity.
3. The general characteristics of the sustained BIC effect are similar to those of the instantaneous BIC effect. That is, the same general relationships hold between the change in conductance, the primary electron-beam bombarding voltage, and the applied field across the dielectric.
4. The maximum sustained change in conductivity obtained with the present material is about four orders of magnitude. This is for a  $1/2\text{-}\mu$  thick layer, applied voltage - 1.5 V, and primary beam energy 14 kV.

Based on consideration of the theoretical aspects of the effect, it appears that a barrier at the lower electrode plays an important role in the sustained BIC effect. The existence of such a barrier is supported not only by the asymmetrical volt-ampere characteristic but also by the variations in capacitance with applied field and sustained current.

Comparison of the experimental data with the requirements for switching the voltage across the EL layer indicate

1. The BIC layer thickness must be increased from  $1/2\text{ }\mu$  to about  $10\text{ }\mu$ . Alternatively, the EL layer must be reduced in thickness.
2. The unexcited conductance of the BIC layer should be increased by about three orders of magnitude.
3. The change in conductivity as a result of excitation appears adequate.
4. The operating voltages of the BIC layer must be increased from 1.5 V to a range of from 5 to 10 V.

## VI. RECOMMENDATIONS

The future effort should be directed toward producing a sustained BIC layer which is capable of modulating the voltage across the EL layer. The principal changes required in the present layer include increasing the film thickness substantially and increasing the unexcited conductivity. However, if the film thickness is increased to  $10\ \mu$  then the beam energies required to excite such a layer will be impractical. If the present layers can be modified so that the barrier is adjacent to the upper electrode rather than to the bottom electrode, then it may be possible to use a  $10\text{-}\mu$ -thick BIC layer and excite it with low primary electron beam energies. This thickness limitation may also be overcome through the use of dc EL phosphors. In this case the change in conductivity of the thin BIC films may be all that is required to modulate the voltage across the EL layer.

The techniques for increasing the unexcited conductance of the layer appear more straightforward. Thus it would be expected that the addition of impurities will result in a sustained BIC layer with a higher unexcited conductance. The directions to be followed in achieving a thick, more conductive BIC layer with a barrier at the top of the electrode instead of the bottom are as follows:

1. Continue the present investigation of the sustained BIC effect with the objective of establishing the nature of the barrier at the bottom of the electrode. Once having established the nature of the barrier, attempt to reproduce it at the top electrode.
2. Determine whether impurities can be added to the layers to increase the conductivity without an accompanying reduction in the magnitude of the sustained BIC effect.

#### REFERENCES

1. R. Bube, "Mechanisms of photoconductivity in microcrystalline powders," J. Appl. Phys. 31, 2239 (1960).
2. M. A. Lampert, "The role of injecting contacts in photoconductors," J. Phys. Chem. Solids 22, 187 (1960).
3. R. Bube, "Maximizing the performance of photoconductors," Air Force Cambridge Research Laboratories 62, 158 (March 14, 1962).